

Development of the GEBCO World Bathymetry Grid

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1.0 Introduction

1.1 Definition and advantages of a grid

A grid is a computer-based representation of a 3-dimensional (x,y,z) data set. In a gridded database, the z value is given at equidistantly-spaced intervals of x and y . In our case, the GEBCO bathymetric grid, the z value is the depth to the sea floor and is given at evenly-spaced increments of longitude (x) and latitude (y).

Gridded databases are ideally suited for computer-based calculations. In binary form, they are compact and permit sub-sets of the data to be easily extracted. They allow comparison with other gridded databases, and facilitate the plotting, visualisation and ready analysis of the grid values.

1.2 GEBCO recognition for gridded bathymetry

Bathymetry represents a fundamental measure of Earth's physiography. Although climate modellers, oceanographers, geologists, and geophysicists consider bathymetry to be a key parameter in their fields, the world's oceanic areas remain poorly mapped overall. Indeed, the surfaces of the moon, Mars, Venus and numerous planetary satellites are better-surveyed than the ocean floor. That said, GEBCO aims to provide the most accurate global bathymetry data set derived from echo-soundings that is publically-available.

Ten years ago, GEBCO bathymetry was available in one form only: as hard copy printed map sheets. Although a generation of earth scientists had grown familiar with this series of 18 GEBCO portrayals covering the entire globe, the use of paper charts was becoming restrictive. In 1994, GEBCO released on CD-ROM a digitized version of its standard 500m-interval contours. This CD-ROM, called the GEBCO Digital Atlas (GDA) contained data files of digitized contours, a software interface for PC, and a detailed documentation booklet.

The GDA represented the culmination of a decade's work by numerous individuals and institutions around the globe, and the shift from paper charts to digitized contours made the GEBCO contour data set more versatile. However, by the early 1990s, the increasing availability of low-cost, powerful computers meant that the use of gridded databases was becoming widespread. Digitized contours alone did not offer the advantages of a 3-dimensional grid.

At its 1994 annual meeting, the volunteers that comprise the membership of GEBCO's Sub-Committee on Digital Bathymetry (SCDB) recognised the widely-expressed need of earth scientists for a high-quality gridded depth database, and agreed to explore the construction of a gridded version of GEBCO bathymetry, at a grid spacing of 5 arc minutes. An SCDB Grid Working Group was initiated.

At the 1997 GEBCO SCDB meeting, it was agreed that construction of the GEBCO global grid would use as input the latest-available GDA digitized contours and that the resultant grid depths would match these GDA contours as closely as possible. Members of the grid working group were assigned the responsibility of producing particular regional grids. When combined, these regional grids would constitute GEBCO's global bathymetric grid with 100% coverage of the world's oceanic areas.

In 1998, at the next SCDB meeting, it was decided that the grid would contain both sea floor bathymetry and land topography – it would be a continuous digital terrain model. Also at that meeting, the resolution specification of the grid was increased to a spacing of 2.5 arc minutes which would make it comparable in resolution to other earth science global databases. At a subsequent GEBCO meeting, this resolution was increased still further, to a 1-minute grid spacing.

The construction of a gridded depth database from digitized contours posed a number of non-trivial problems and it was early recognized by members of the SCDB Grid Working Group that one method alone could not be used to construct the entire global grid. Evolving technical developments and gridding techniques would result in each

regional grid having a unique character that would reflect the style of contouring, the method of grid construction, and location of region. However, the edge match between adjacent regional grids would be seamless.

The minutes from recent GEBCO meetings provide a detailed summary of the development of the GEBCO 1-minute bathymetric grid. These minutes can be found on GEBCO's web site: <http://www.ngdc.noaa.gov/mgg/gebco/gebco.html>

2.0 Developers of regional grids

The formidable task surrounding the compilation of source echo-soundings and their subsequent interpretation by bathymetrists to produce the GEBCO GDA contours is described fully in the GDA documentation. Like the compilation of those GDA contours, the construction of the GEBCO 1-minute global bathymetric grid has almost exclusively been the result of a purely voluntary effort by a number of scientists and institutions around the globe.

Shown in Figure 1 are the regional grids that comprise the GEBCO global 1-minute bathymetric grid. The GEBCO member or group responsible for creating each of these grids is listed below. Input data sources – soundings and contours – that were used in addition to the main GDA contours are also given.

Digitization of the GDA contours, track lines, and coastline data was performed by Pauline Weatherall at the British Oceanographic Data Centre (BODC). Supplemental digitization was provided by the organisations referenced in the User Guide to the GDA Data Sets.

Edge-matching and the editing of GDA contours along common grid boundaries was performed by Pauline Weatherall (BODC).

The current contact details of GEBCO members can be found on GEBCO's web page at <http://www.ngdc.noaa.gov/mgg/gebco/gebcoalphabetical.html>

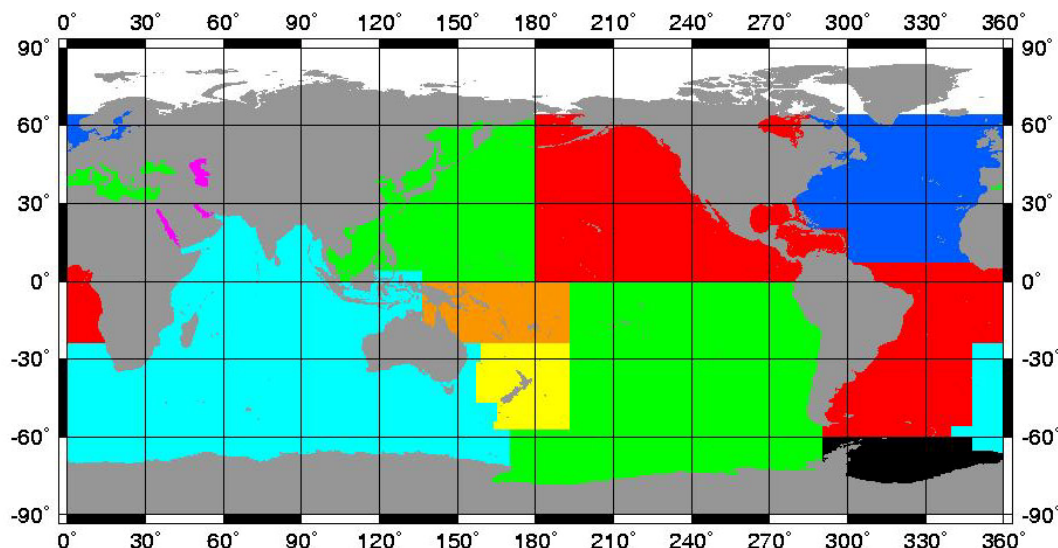


Figure 1. The main regional grids of the GEBCO 1-minute global grid are identified by section number as follows. Light blue – 2.1. White – 2.2. Red – 2.3. Green – 2.4. Black – 2.5. Dark blue – 2.6/2.11. Fuchsia – 2.7. Orange – 2.8. Yellow – 2.9.

2.1 Indian Ocean and Environs

Andrew Goodwillie: from the extensive new bathymetric data compilation and contour interpretation by Robert Fisher. The grid includes additional intermediate-level contours in abyssal plains and the Bay of Bengal, and South African shallow-water shelf contours.

2.2 Arctic Ocean (64° N to North Pole)

Martin Jakobsson and Ron Macnab: from the IBCAO (Arctic Ocean) compilation. <http://www.ngdc.noaa.gov/mgg/ibcao/ibcao.html>

2.3 South Atlantic, NE Pacific, Gulf of Mexico, portions of N Atlantic, Hudson Bay

William Rankin: Includes data from the IBCCA (Caribbean and Gulf of Mexico) compilation, and from Germany, UK and USA. <http://www.ngdc.noaa.gov/mgg/ibcca/ibcca.html>

2.4 NW Pacific, SE Pacific, Mediterranean Sea, Black Sea

Michael Carron: includes Japanese shelf data and additional US data.

2.5 Weddell Sea

Hans-Werner Schenke: largely from original Antarctic bathymetric data collected by Alfred-Wegener-Institut für Polar-und Meeresforschung.

2.6 North Atlantic (large portions)

Peter Hunter and Ron Macnab: Includes data supplied by Canada, France, UK and USA.

2.7 Red Sea, Caspian Sea, Persian Gulf

John Hall: includes IBCM data and major data contributions from Russia, France, Israel. <http://www.ngdc.noaa.gov/mgg/ibcm/ibcm.html>

2.8 Equatorial Western Pacific

Lois C. Varnado.

2.9 New Zealand waters

National Institute of Water and Atmospheric Research, New Zealand.
<http://www.niwa.cri.nz/>

2.10 USA Continental Shelf

High-resolution bathymetric grid provided by National Geophysical Data Center, Boulder. <http://www.ngdc.noaa.gov/mgg/coastal/coastal.html>

2.11 Baltic Sea

Torsten Seifert: Institut für Ostseeforschung Warnemuende, Germany.

2.12 Japan region, shallow water

Japan Meteorological Office. From Japan Hydrographic Office data.

3.0 Gridding method

Below, is summarised the general methodology that was used for the construction of most of the GEBCO regional grids. This summary is intended to be an overview to the gridding process. It does not cover the techniques that were used by all GEBCO gridders.

Refer to the individual GEBCO gridders listed in section 2 and to the references therein for specific information on gridding techniques.

GEBCO gridders made much use of the Wessel and Smith **GMT** software for construction and quality control of the grids (<http://gmt.soest.hawaii.edu/>).

Each regional grid was divided into smaller sub-grids, generally of 10x10 degrees. This had the advantage of rapid computation of the interpolated bathymetric grid values and of facilitating the task of error-checking the resultant grid depths.

In constructing each 10°x10° sub-grid an additional border of 5 degrees was added. This 5° overlap helped to maintain the continuity and smoothness of the grid surface such that step function depth discontinuities along common edges were minimised when adjacent 10°x10° sub-grids were joined together.

3.1 Accumulation of input data

One input data file, in (longitude, latitude, depth) format, is created. It contains:

- Digitized current GEBCO GDA contours
- GLOBE land elevations
- WVS coastlines
- SCAR (Antarctic) coastlines
- Additional shallow-water contours and soundings
- Additional intermediate contours in featureless areas
- Additional individual echo-soundings

3.2 Decimation of input data

Divide the area of the sub-grid into 1x1 arc minute bins: use a median filter (*GMT: blockmedian*) or mean filter (*GMT: blockmean*) to thin the data points within each 1x1 minute bin. This acts to reduce the effect of erratic input data and it speeds up the grid computation. Note that, at this decimation stage, bins that contain no input data points remain empty.

GMT command example, for the sub-grid bounded by 150°-160° E/20°-30° S:

```
% blockmedian input_data.xyz -R145/165/-35/-15 -I1m -V > input_data.bm
```

3.3 Compute a 3-D gridded surface

The 1x1 minute thinned data file is fed into a surface-fitting computer program (*GMT: surface*) which uses as its interpolation algorithm a 3-D bi-cubic spline under tension. This program computes a depth value at each grid node. By this process of interpolation each 1x1 minute bin in the 10°x10° sub-grid is now associated with an interpolated depth value.

GMT command example:

```
% surface input_data.bm -R145/165/-35/-15 -I1m -C1 -T0.35 -V -Gtemp.grd  
% grdcut temp.grd -R150/160/-30/-20 -V -Ggrid_150e_160e_30s_20s.grd
```

3.4 Compare grid depths to the input GDA contours

Recall from section 1.2 that the prime requirement of the GEBCO gridded bathymetry is that it matches – as closely as possible – the input GDA contours. Forcing a rigorous 3-D mathematical grid model to fit the interpreted geological characteristics that are built into the GDA contours can never result in a perfect match. These mis-matches are present as artefacts in the resultant grid.

The most convenient way of comparing the grid depths and input depths is found to be by visual means. Plots made in a Mercator projection at a scale of 4 inches to one degree (about 1:1 million at the equator) allow even the smallest of artefacts to be investigated, as follows.

The gridded bathymetry is plotted in plan view as a coloured surface. It is overlain by the digitized input GDA contours. With colour palette changes specified at the same depths as the input GDA contours any colour change that is not bounded by a GDA contour is considered to be an artefact. This simple visual technique allows gross gridding mis-matches to be readily seen. The use of artificial illumination on these plots reveals more subtle grid artefacts many of which lie within one colour palette band.

3.5 Main types of grid errors

The most common grid artefacts were over-shoots in areas of relatively steep topography. The 500m standard GEBCO contour interval and the overall lack of shallow-water data caused many over-shoots at the tops and bases of continental shelves, seamount summits, ridges, rises and plateaux. (See Figure 5.1 in Appendix A for an example of an overshoot.)

Another common artefact, due to the general absence of finer-interval contours in relatively featureless abyssal plains, sediment fans, basins and wide continental shelves, produced extensive areas of erroneous depths.

In some regions, an unexpected source of gridding error came from GDA contours that had been digitized at a relatively sparse along-contour sampling interval.

More minor artefacts were produced by mis-labelled GDA contours and by some unreliable echo-soundings that were used as additional input.

3.6 Minimisation of grid artefacts

3.6.1 Adjustment of the grid surface tension factor (see section 3.3) could reduce the over-shoots but could also produce mis-matches elsewhere in the grid. For consistency each gridded used one tension factor within their grids. A tension factor of 0.35 was found to be appropriate for a wide range of bathymetric features.

3.6.2 Ideally, a grid is produced by the gridding of at least one data point per bin. In the case of the GEBCO global bathymetric grid, there are many 1x1-minute bins that are devoid of digitized GDA contour input data.

In areas of widely-spaced contours such as abyssal plains and wide continental shelves it was essential to help constrain the grid calculation through the addition of echo-soundings and intermediate-level contours. Gridders reverted, where possible, to the original data compilation sheets created by the bathymetrists. Even so, the effort required to meticulously compile additional constraining data was large, particularly the drawing and digitization of intermediate-level contours and the manual key-entering of individual reliable echo-sounding depths.

After these additional constraining points are added to the input data file (step 3.1), steps 3.2–3.4 are repeated until all gridding artefacts are minimized.

3.6.3 Once GEBCO gridders gained insight into the nuances of their gridding procedures, it was possible to pre-emptively address portions of the grid that had a high potential for otherwise producing grid artefacts: before making the grid, extra depth values in these flagged areas were added to the input data file. This greatly reduced the number of iterations that needed to be performed before a grid was considered finished.

3.7 Antarctic coastlines

In the Indian Ocean, Antarctic (SCAR) coastlines with SCAR codes of 22010-22023 were considered to be permanent ice or other permanent coastline. They were taken to have a depth of 0 meters. Depths beneath permanent ice were not determined.

Floating and seasonal ice edges (SCAR coastlines coded 22030-22050) were excluded from the gridding process. In these locations, the underlying sea floor was modelled by *surface* from surrounding bathymetry and permanent coastlines.

3.8 Main exceptions to general gridding methodology

Refer to the individual GEBCO gridders listed in section 2 and to the references therein for specific information on gridding techniques.

3.8.1 The Arctic Ocean grid was constructed on a polar stereographic projection. And, its primary source of bathymetric data is from previously-unavailable digital echo-soundings and contours.

3.8.2 GDA contours in the S Atlantic, NW and SE Pacific are only sparsely sampled in the along-contour direction. For these areas it was necessary to interpolate more

digitized points along-contour in order to ensure the presence of at least one digitized contour point for every arc minute of contour length.

3.8.3 Grids for the S Atlantic, NW and SE Pacific did not use land elevations in the original input data. Instead, after the bathymetric grid had been accepted, grid values above sea-level were replaced with GLOBE values.

3.8.4 Grids for the Red Sea, Caspian Sea, and Persian Gulf were constructed at a spacing of 0.1-minutes and then degraded to 1-minute for inclusion in the GEBCO global grid.

3.8.5 The high-resolution US Continental Shelf Coastal Relief Model was degraded to 1-minute for inclusion in the GEBCO global bathymetric grid.

3.9 Related web links and references:

Land elevations: GLOBE (v2): <http://www.ngdc.noaa.gov/seg/topo/globe.shtml>

US Coastal Relief Model: <http://www.ngdc.noaa.gov/mgg/coastal/coastal.html>

SCAR (v3) coastlines: http://www.nerc-bas.ac.uk/public/magic/add_main.html

WVS coastline (NIMA): <http://rimmer.ngdc.noaa.gov/coast/wvs.html>

GMT software: <http://gmt.soest.hawaii.edu/>

Jakobsson, M., Cherkis, N., Woodward, J., Coakley, B., and Macnab, R., 2000, A new grid of Arctic bathymetry: A significant resource for scientists and mapmakers, *EOS Transactions*, American Geophysical Union, v. **81**, no. 9, p. 89.

Goodwillie, A. M., 1996. Producing Gridded Databases Directly From Contour Maps. University of California, San Diego, Scripps Institution of Oceanography, La Jolla, CA. *SIO Reference Series* No. **96-17**, 33p.

4.0 Assessing the quality of the grid

The prime goal in the construction of the GEBCO 1-minute global bathymetric grid was to match – as closely as possible – the input GDA contours. A grid that replicates the input depths exhibits no difference between the mathematically-modelled grid depths and the input depths. Any non-zero differences indicate mis-matches introduced by the 3-D surface-fitting process.

To quantify these differences one can extract (*GMT: **grdtrack***) grid depths at the same locations as the input digitized GDA contours (and at any additional non-GDA contours and soundings). Differencing the grid and input depth values gives a measure of the closeness of fit of the gridded surface. As an example, the $10^{\circ} \times 10^{\circ}$ sub-grids in the Indian Ocean typically yield 95% of grid depth values within 50m of the input depth values. In areas generally devoid of GDA contours such as extensive abyssal plains, this differencing method will allow us to quantify the closeness of fit only if additional input contours and soundings were used there.

Assessing grid quality simply as a difference between grid and input depths fails to take into account the wealth of data and expert geological knowledge that were used by the bathymetrists to painstakingly construct the GDA contours. Each bathymetrist used their own unique set of criteria to produce these contours. Thus, some measure of the quality of the contouring is perhaps more useful than a statistic determined from the grid depths. However, the subjective and interpretative nature of these GDA contours makes even their assessment difficult.

One approach to deriving a measure of contour quality is to create geographic plots showing the distribution of the raw data used to derive the bathymetric GDA contours: shipboard echo-soundings lines and any additional soundings. This allows us to judge the reliability of the GDA contours. Care must be taken over the type of map projection chosen to ensure a balanced view of track line density. A track plot, however, does not take into account the large number of additional contours from numerous sources that were used in the derivation of GDA contours and of the grid. And, it could include portions of digitized track lines for which the bathymetrist had deemed the soundings unreliable.

Alternatively, a geographic plot showing the distribution of *all* digitized data that were used as input to the gridding process - GDA contours, additional non-GDA contours, individual additional echo-soundings, and any along-track soundings - would accurately show their areal coverage. This provides a measure of the distance

of a grid point to the nearest input (constraining) data point but tells us nothing of the accuracy of the grid depths.

In summary, attempting to impose an all-encompassing numerical quality factor – whether statistically-determined or otherwise – upon the grid and upon the subjectively-derived GDA contours is not straight-forward. The difficulty in producing grids from disparate data sources and in assessing their quality is discussed extensively in Appendix A. Contact the gridder listed in section 2 for specific details of how the quality of their grids was measured.

5.0 Limitations of the GEBCO grid

5.1 GEBCO, traditionally, has concentrated upon the interpretation of bathymetry in deep water. For decades, its standard contours have been fixed at intervals of 500m (500m, 1000m, 1500m, 2000m, etc.) with a 200m and 100m contour in shallow zones only where justified. Although significant quantities of bathymetry data contoured at intervals of 200m and even 100m have been incorporated into GEBCO bathymetry, the standard 500m contours comprise the bulk of the current GEBCO GDA contour data set. Their style and character is unique, reflecting the interpretative skill and experience of each of the GEBCO contourers.

Plotting the grid depths as a histogram reveals numerous peaks each of which occurs at a multiple of 500m. These peaks correspond to the 500m contour interval of the input digitized GDA contour data. This *terracing* effect is a well-known problem of constructing grids from contours.

5.2 It is conceivable that a bathymetric feature of up to 500m in height would be excluded from the GDA contours if its base and peak fall just inside a 500m-level contour. However, by careful examination of the source echo-soundings data the bathymetrists strove to avoid this scenario by ensuring that there was some indication in the resultant bathymetric contours of the presence of such a feature.

5.3 The standard GEBCO contour interval is 500m. In some locations, additional intermediate contours (at the 200m or 100m interval) were used to constrain the grid calculation. And, on some continental shelves, very shallow contours were input. Compared to total-coverage, high-resolution multi-beam bathymetric surveys it will likely prove unjustifiable to plot the GEBCO global grid at a fine contour interval of, say, 10m or 20m except in very rare cases (where contours of this interval size were used as input).

5.4 The 1x1-minute bin size used in the GEBCO global bathymetric grid does not imply that input data were this densely distributed. See section 4.0. Even after the inclusion of much additional constraining contours and soundings data, many 1x1-minute bins remained unpopulated.

5.5 The 1x1-minute bins become thinned in the E-W direction away from the equator which results in non-uniform grid interpolation. This latitude-dependent distortion of bin geometry required that the Arctic Ocean grid be constructed using a specialized method (see section 2). Except for the Arctic Ocean this distortion was considered an acceptable compromise of the generalized gridding method described in section 3. Assuming a spherical earth, the 1x1-minute bin dimensions vary with latitude as follows:

| Latitude (N or S) | Bin width (E-W) | Bin height (N-S) |
|----------------------|--------------------|---------------------|
| 0° | 1.85 km | 1.85 km |
| 30° | 1.60 km | 1.85 km |
| 45° | 1.31 km | 1.85 km |
| 60° | 0.92 km | 1.85 km |
| 72° | 0.57 km | 1.85 km |

5.6 Due to the colossal size of the geographical areas gridded and to the number of grid artefacts found, only grid mis-matches of more than a few kilometers in size were investigated and eliminated or reduced.

5.7 No thorough error-checking was performed for land areas. The very high density of GLOBE land elevation data was taken as accurate.

5.8 The grid is not intended to be used for navigational purposes.

6.0 Format and compatibility of grid

The GEBCO 1-minute global bathymetric grid is grid-node registered and has a longitude range of 0° - 360° (0 - 180° E/W) and a latitude range of 90° N - 90° S. It is in netCDF format to ensure compatibility with the **GMT** software package. Bathymetry is given as integer depths in corrected meters. Land areas contain heights above sea-level in integer meters.

6.1 Accessing the GEBCO 1-minute bathymetric grid

UNIX users can access the full-resolution 1-minute gridded bathymetry data directly from the CD-ROM where it is stored as one global **GMT**-compatible netCDF data file. This global grid file is stored in /cdrom/grid/gridone.grd. The **GMT** command **grdcut** can be used to extract a portion of grid data. Example, with the CD-ROM mounted on /cdrom, to extract GEBCO gridded bathymetry for the region 120° - 134° E, 3° N - 10° S we could use:

```
% grdcut /cdrom/grid/gridone.grd -R120/134/-10/3 -V -Ggebco.grd
```

For PC users running Microsoft Windows, the bathymetric grid is accessed via the PC software interface. The gridded bathymetric data can be exported as a netCDF **GMT**-compatible grid file and in ASCII formats of (longitude,latitude,depth) and depth only.

6.2 Accessing GEBCO vector data

Three vector data sets contained on the GEBCO CD-ROM (digitized GDA contours, digitized ship tracks, digitized SCAR coastlines) are stored in both binary and ASCII format. A fourth vector data set, the digitized WVS coastline, is stored as binary only.

The binary-formatted vector files are accessed via the PC software interface: the binary vector data can be exported in two commonly-used GIS formats - DXF and ESRI Shapefiles - and also in simple ASCII column and row format.

The ASCII-formatted vector data files allow direct access from UNIX and PC platforms and are compatible with *GMT* programs such as *psxy*. These ASCII vector files are segment-separated with a one-line header separating each segment. This header has “>” as the first character, a feature code and the number of digitized points within the segment. The one-line header is followed by the digitized (latitude,longitude) pairs which are given in decimal degrees. Here is an example of a segment of an ASCII vector data file. It is for a digitized 2500m GDA bathymetric contour which has six digitized points in this segment:

```
> 2500 6
6.0670 133.9230
6.0470 133.9080
6.0560 133.8990
6.1040 133.9200
6.0910 133.9300
6.0670 133.9230
```

7.0 Updating the GEBCO grid

The GEBCO 1-minute global bathymetric grid is not intended to be a static database. Instead, the bathymetric grid will continuously evolve through the inclusion of new or improved data sets as these become available.

It is envisioned that the mechanism of updating the GEBCO grid will mainly be achieved through the incorporation of quality-controlled digital echo-soundings data directly into the gridding process, without the resource-intensive, multi-year step of first re-compiling all echo-soundings and re-contouring an area. However, for regions in which revised bathymetry is provided only as digitized contours, an update for that portion of the grid will revert to the methods described in section 3.

8.0 How to give feedback and become involved with GEBCO

We need your feedback! If you have detected any problems in the GEBCO global bathymetric grid, the vector data sets, the software interface or in this documentation please let us know. You can contact GEBCO via the “Contact us” button on GEBCO’s home web page: <http://www.ngdc.noaa.gov/mgg/gebco/gebco.html>

GEBCO is a largely voluntary group of individuals and organizations that share a common vision: the provision of the best-available bathymetry for the world’s oceans. As a scientific association we welcome your ideas and suggestions and we invite you to become an active member of GEBCO.

Of course, if you are willing to contribute any bathymetric data sets (cruise files, data compilations, soundings sheets, and so on) that are not already part of the GEBCO bathymetric compilation this would be greatly appreciated. All contributions will be fully accredited and acknowledged.

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